(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 481 465 A1**

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: **91117679.0**

(22) Date of filing: **16.10.91**

(51) Int. Cl.5: **H01J 31/50**, H01J 29/38, H01J 9/12

(30) Priority: **18.10.90 JP 277676/90**

(43) Date of publication of application: **22.04.92 Bulletin 92/17**

(84) Designated Contracting States: **DE FR GB**

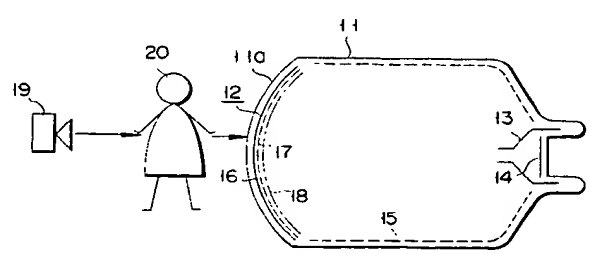
(71) Applicant: **Kabushiki Kaisha Toshiba**
72, Horikawa-cho Saiwai-ku
Kawasaki-shi(JP)

(72) Inventor: **Kubo, Hiroshi, c/o Intellectual Prop. Division**
Kabushiki Kaisha Toshiba, 1-1 Shibaura 1-chome
Minato-ku, Tokyo 105(JP)

(74) Representative: **Henkel, Feiler, Hänzel & Partner**
Möhlstrasse 37
W-8000 München 80(DE)

(54) **X-ray imaging tube and method of manufacturing the same.**

(57) An X-ray imaging tube which comprises a vacuum envelope (11), an input screen (12) comprising a substrate (16) located in the input end of the envelope (11), an input phosphor layer (17) formed on the substrate (11) and comprising a number of columnar phosphor crystals (17a), and a photoelectric layer (18) formed directly or indirectly on the input phosphor layer (17), an anode (13) and an output screen (14) located in the output end of the envelope, and a beam-converging electrode (15) located in the envelope (11) and extending along the inner surface of the envelope (11). The tube further comprising optically opaque layers (21) which are formed in each columnar crystal (17a) and extending from the surface thereof. A method of manufacturing an X-ray imaging tube, disclosed herein, comprises the steps of vapor-depositing a predetermined phosphor on a substrate (16), thereby forming on the substrate (16) an input phosphor layer (17) consisting of columnar crystals (17a), vapor-depositing a predetermined material, thereby forming an optically opaque layer (21) on the tip of each columnar crystal (17a), sputtering the optically opaque layer (21), thereby removing a part of the optically opaque layer (21) formed on the tip of the columnar crystal (17a), vapor-depositing said predetermined phosphor, and, if necessary, repeating these steps, thereby forming a plurality of optically opaque layers (21) in each columnar crystal (17a), which extend from circumferential surface of the columnar crystal (17a).



F I G. 2

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The present invention relates to an X-ray imaging tube and a method of manufacturing the same, and more particularly to an X-ray imaging tube having an improved input screen.

An X-ray imaging tube is a device which comprises a vacuum envelope having an input end and an output end, an input window closing the input end of the envelope, an input screen located within the envelope and opposing the input window, an anode provided within the output end of the envelope, an output screen located in the output end of the envelope, and beam converging electrodes arranged within the envelope, coaxial with each other, and spaced apart in the axial direction of the envelope 1. The input screen comprises a substrate, a phosphor layer formed on the substrate, and a photoelectric layer formed on the phosphor layer.

In operation, X-rays applied to a subject and passing through it are applied to the input screen through the input window. They pass through the substrate, reaching the phosphor layer. The phosphor layer converts the X-rays into light. The photoelectric layer converts the light into electron beams. The beam-converging electrodes converge the electron beams, and the anode accelerates these electron beams. The electron beams are applied to the phosphor layer of the output screen, which emits rays corresponding to the X-rays, forming an X-ray image of the object. Hence, the X-rays are applied to a visible image. This image is recorded by means of a TV camera, a movie camera, a spot camera, or the like. The X-ray image thus recorded is used for diagnosis.

One of the important characteristics of an X-ray imaging tube of this type is its resolving power, i.e., the ability of producing smallest possible separable images of different points on an object. One of the factors determining the resolution is the quality of the input screen of the X-ray imaging tube.

Fig. 1 is an enlarged view of the input screen of a conventional X-ray imaging tube. As can be seen from Fig. 1, the input screen comprises a substrate 1, an input phosphor layer 2 formed on the substrate 1, and a photoelectric layer 3 formed on the phosphor layer 2. The substrate 1 is made of material having high X-ray transparent, such as aluminum or an aluminum alloy. The input phosphor layer 2 is made of material having high X-ray conversion efficiency, such as cesium iodide activated by sodium (CsI:Na). The photoelectric layer 3 is a multi-layer member made of photoelectric materials such as antimony and alkali metal. As is evident from Fig. 1, the input phosphor layer 2 consists of a number of columnar phosphor crystals 2a.

In the columnar phosphor crystals 2a, X rays 4 applied through the substrate are converted into light beams 5. The light beams 5 propagate in all directions. Those of the beams, which propagate onto circumferential surface of each columnar crystal 2a at incidence angle equal to or greater than 33°C, i.e., the critical angle D of CsI:Na, are reflected totally and, hence, do not degrade the resolution of the X-ray imaging tube. However, those light beams which propagate onto circumferential surface of each crystal 2a at incidence angle less than the critical angle D of CsI:Na propagate into the adjacent columnar crystals 2a, acting as scattering-light therein and inevitably degrading the resolution of the X-ray imaging tube.

Accordingly, it is the object of the present invention to provide an X-ray imaging tube in which the light beams propagating sideways in the input screen are absorbed or reflected before they reach the photoelectric layer of the input screen, and which thereby has high resolution, and also to provide a method of manufacturing this X-ray imaging tube.

According to the invention, there is provided an X-ray imaging tube which comprises: a vacuum envelope having an input end and an output end; an input screen comprising a substrate located in the input end of the envelope, an input phosphor layer formed on the substrate and comprising a number of columnar phosphor crystals, and a photoelectric layer formed directly or indirectly on the input phosphor layer; an anode located in the output end of the envelope; a beam-converging electrode located in the envelope and extending along the inner surface of the envelope; and a plurality of optically opaque layers formed in each columnar crystal and extending from the surface thereof.

According to this invention, there is provided a method of manufacturing an X-ray imaging tube, comprising the steps of: vapor-depositing a predetermined phosphor on a substrate, thereby forming on the substrate an input phosphor layer consisting of a number of columnar crystals; vapor-depositing a predetermined material, thereby forming an optically opaque layer on the tip of each columnar crystal; sputtering the surface of the optically opaque layer, thereby removing a part of the optically opaque layer formed on the tip of the columnar crystal; vapor-depositing said predetermined phosphor; and, if necessary, repeating these steps, thereby forming a plurality of optically opaque layers in each columnar crystal, which extend from circumferential surface of the columnar crystal.

Since the optically opaque layers extend from circumferential surface of each columnar crystal toward the inside thereof, they absorb or reflect any light beam propagating sideways, before the light beam reaches the photoelectric layer. The input screen, having the optically opaque layers,

can prevent degradation of the resolution of the X-ray imaging tube. In other words, it helps to impart high resolution to the X-ray imaging tube.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is an enlarged, cross-sectional view showing the input screen of a conventional X-ray imaging tube;

Fig. 2 is a cross-sectional view, schematically showing an X-ray imaging tube according to one embodiment of the present invention;

Fig. 3 is an enlarged, cross-sectional view showing the input screen of the X-ray imaging shown in Fig. 2;

Fig. 4 is a sectional view, explaining one of the steps of a method of manufacturing the X-ray imaging tube shown in Fig. 2;

Fig. 5 is a sectional view, explaining another steps of the method;

Fig. 6 is a sectional view, explaining still another step of the method;

Fig. 7 is a sectional view, explaining another step of the method;

Fig. 8 is a sectional view, explaining another step of the method; and

Fig. 9 is a sectional view, explaining still another step of the method.

An X-ray imaging tube according to the invention has the structure illustrated in Fig. 2. As is evident form Fig. 2, the X-ray imaging tube comprises a vacuum envelope 11, an input window 11a closing the input end of the envelope 11, an input screen 12 located in the input end of the envelope 11 and opposing the input window 11a, an anode 13 located in the output end of the envelope 11, and beam-converging electrode 15 provided in the envelope 11 and extending along the inner surface thereof. The input window 11a is made of material having high X-ray transparent, such as aluminum or an aluminum alloy. The input screen 12 comprises a substrate 16 made of material having high X-ray transparent, such as aluminum or an aluminum alloy, a input phosphor layer 17 formed on the substrate 16 and made of material having high X-ray conversion efficiency, such as cesium iodide activated by sodium (CsI:Na), and a photoelectric layer 18 formed on the layer 17. The layer 18 is a multi-layer member made of photoelectric materials such as antimony and alkali metal. (Shown also in Fig. 2 are: an X-ray tube 19, and an subject 20.)

Fig. 3 is an enlarged, cross-sectional view of the input screen 12. As this figure clearly shows, the input phosphor layer 17 is formed on the substrate 16, and the photoelectric layer 18 are formed on the input phosphor layer 17. The input phosphor layer 17 consists of a number of columnar phosphor crystals 17a, extending perpendicular to the the substrate 16 and spaced apart from each other with a gap between them. Each columnar crystal 17a has a square section, one side being about 10 µm long.

In the case where the columnar crystals 17a have refraction index of 1.84, any light beam applied to circumferential surface of each crystal 17a at an incidence angle of equal to or greater than 33° is reflected totally and does not emerge from the columnar crystal 17a at all. Hence, this light beam by no means degrade the resolution of the X-ray imaging tube. However, any light beam applied to circumferential surface of the columnar crystal 17a at an incidence angle less than 33° is reflected totally and emerges from the columnar crystal 17a, inevitably reducing the resolution of the X-ray imaging tube.

In the present invention, in order to prevent such degradation of resolution, a plurality of optically opaque layers 21 made of, for example, aluminum, is formed in each columnar crystal 17a, extending from circumferential surface of the crystal toward the axis thereof. More specifically, these layers 21 are formed in that portion 22 of the crystal 17a which is longer than B x tan 33°. Each optically opaque layer 21 inclines such that its inner end 23 is located nearer the photoelectric layer 18 than its outer end 24. Inclining this way, the layer 21 either absorbs or reflects any light beam propagating to its circumferential surface at an incidence angle of less 33°. As a result, such a light beam never reaches the photoelectric layer 18.

It is desirable that the optically opaque layers 21 be located as near the photoelectric layer 18 as possible. This is because the light beams converted from X rays in that portion of each columnar crystal 17a which is close to the photoelectric layer 18 reach the photoelectric layer 18, without propagating to the optically opaque layers 21 formed in the columnar crystal 17a.

It will now be described how the optically opaque layers 21 are formed in each of the columnar crystals 17a forming the input phosphor layer 17.

First, as is shown in Fig. 4, CsI:Na is evaporated in a vapor source 26, and is applied from the source 26 to the substrate 16. Hence, CsI:Na is vapor-deposited, thereby forming columnar crystals 17a on the substrate 16. The tip $17a_1$ of each columnar crystal 17a is shaped like a cone. (In Fig. 4 which is a cross-sectional view, the tip $17a_1$ is in the form of an isosceles triangle.) Next, as is shown in Fig. 5, the vapor deposition of CsI:Na is stopped, and aluminum is vapor-deposited on the tips $17a_1$ of the columnar crystals 17a, forming an optically opaque layer 27 on the tip $17a_1$ of each

columnar crystal 17a. Further, as is shown in Fig. 6, ions particles 28, such as Ar^+ or F^+, are impinged at an angle of, for example, 30°, upon the selected portion of the opaque layer 27. As a result, this portion of the layer 27 is removed, only the remaining portion is left on the tip 27 of each columnar crystal 17a. Then, as is shown in Fig. 8, CsI:Na is vapor-deposited on the tip $17a_1$ of each columnar crystal 17a, thus forming a columnar crystal 17a' on the tip $17a_1$. As a result of this, an optically opaque layer 21 having a thickness of 100Å is formed in the columnar crystal 17a. Thereafter, the steps explained with reference to Figs. 5, 6, 7, and 8 are repeated until a plurality of optically opaque layers 21 are formed in the circumferential surface of each columnar crystal 17a as is illustrated in Fig. 9.

According to the present invention, the optically opaque layers 21 can be formed of not only aluminum, but also chromium (Cr), nickel (Ni) or nickel-chrome alloy.

The materials of the components forming the input screen 12 are not limited to those specified above. Rather, other materials can be used, so far as they serve to achieve the object of the present invention.

As has been described above, a plurality of optically opaque layers 21 is formed in the circumferential surface of each columnar crystal 17. These layers 21 absorb or reflect any light beam propagating sideways, before the light beam reaches the photoelectric layer 18. The input screen 12, having the optically opaque layers 21, can prevent degradation of the resolving power of the X-ray imaging tube. In other words, it helps to impart high resolution to the X-ray imaging tube.

When the present invention was applied to an X-ray imaging tube whose input screen has an effective diameter of 9 inches, the tube exhibited resolution of 60ℓp/cm, whereas the conventional X-ray image tube having a 9-inch input screen had only 50ℓp/cm.

Claims

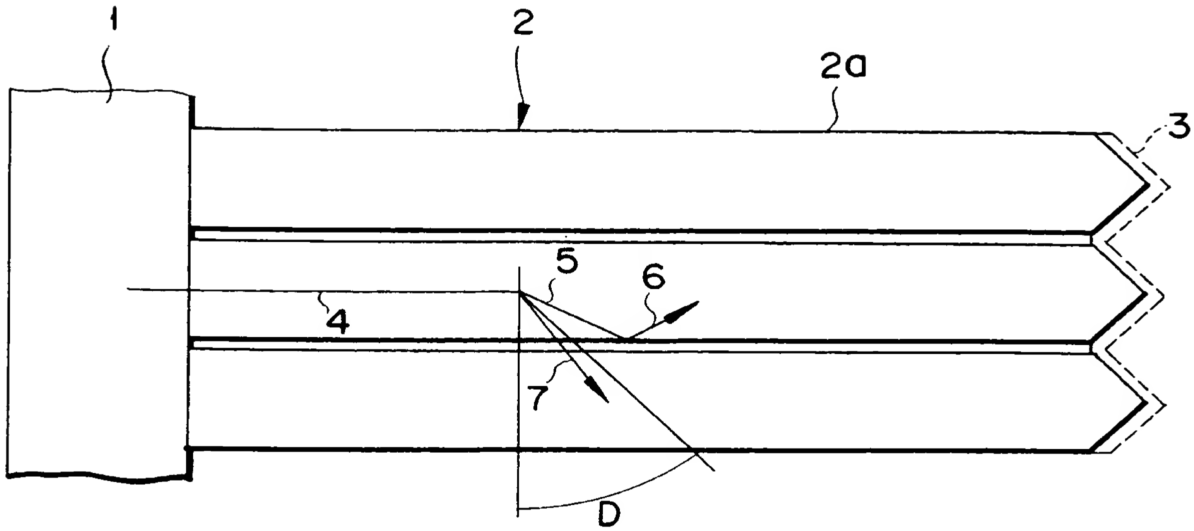
1. An X-ray imaging tube which comprises:
   a vacuum envelope (11) having an input end and an output end;
   an input screen (12) comprising a substrate (16) located in the input end of said envelope (11), an input phosphor layer (17) formed on said substrate (16) and comprising a number of columnar phosphor crystals (17a), and a photoelectric layer (18) formed directly or indirectly on said input phosphor layer (17);
   an output screen (14) located in the output end of said envelope (11);
   an anode located (13) in the output end of said envelope (11);
   a beam-converging electrode (15) located in said envelope (11) and extending along the inner surface of said envelope (11); and
   a plurality of optically opaque layers (21) formed in each columnar crystal and extending from the surface thereof.

2. An X-ray imaging tube according to claim 1, characterized in that said optically opaque layers (21) are made of a metal selected from the group consisting of aluminum, chromium, and nickel.

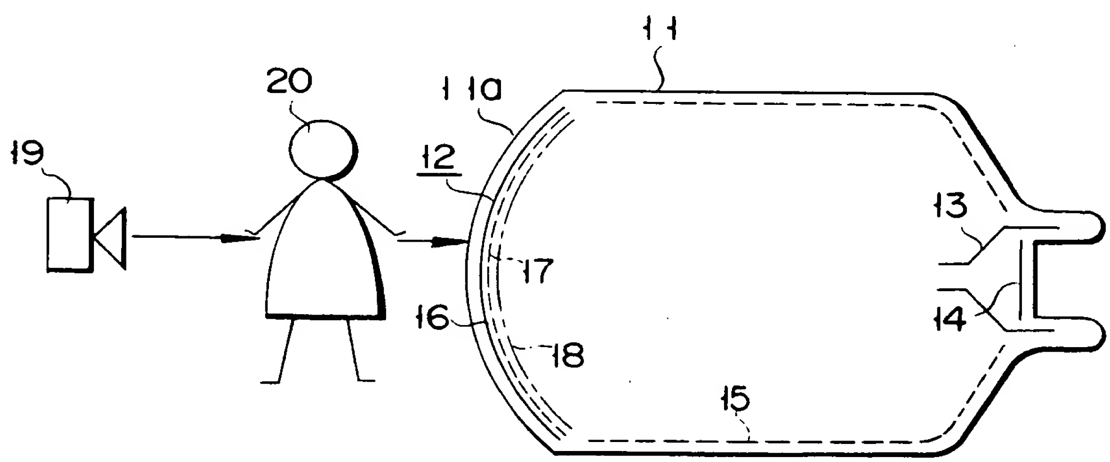
3. A method of manufacturing an X-ray imaging tube, comprising the steps of:
   vapor-depositing a predetermined phosphor on a substrate (16), thereby forming on said substrate (16) an input phosphor layer (17) consisting of a number of columnar crystals (17a);
   vapor-depositing a predetermined material, thereby forming an optically opaque layer (21) on the tip of each columnar crystal (17a);
   sputtering said surface of said optically opaque layer (21), thereby removing a part of said optically opaque layer (21) formed on the tip of said columnar crystal (17a);
   vapor-depositing said predetermined phosphor; and
   repeating these steps, if necessary, thereby forming a plurality of optically opaque layers (21) in each columnar crystal (17a), which extend from circumferential surface of the columnar crystal (17a).

4. A method according to claim 3, characterized in that the ion gas used in sputtering said surface of said optically opaque layer is one selected from the group consisting of Ar^+ and F^+.

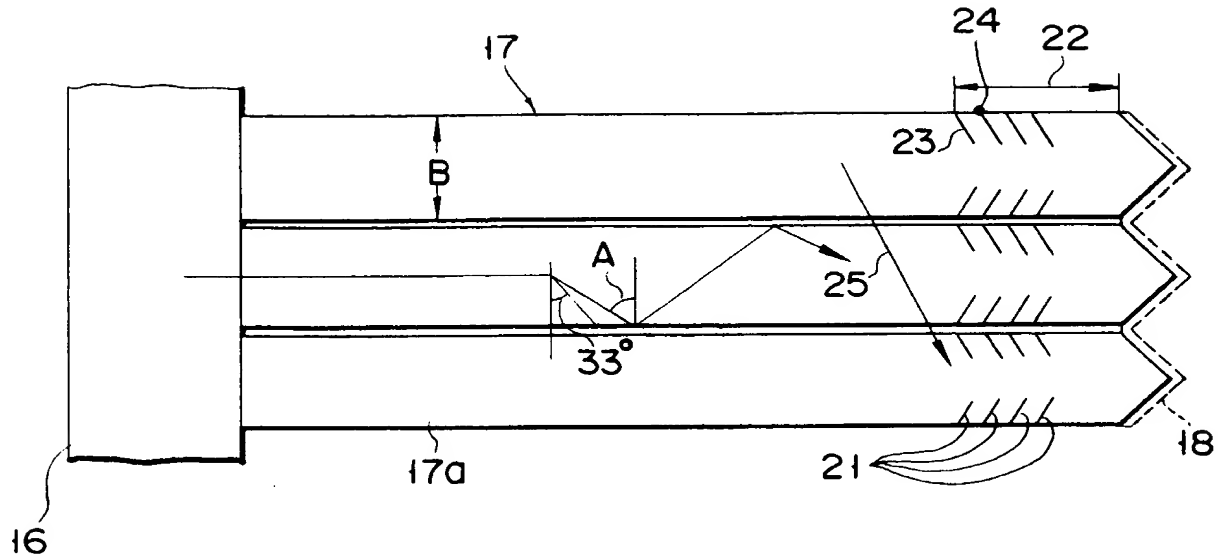
5. A method according to claim 3, characterized in that the ion gas used in sputtering said surface of said optically opaque layer is one selected from the group consisting of Ar^+, F^+, Xe^+.



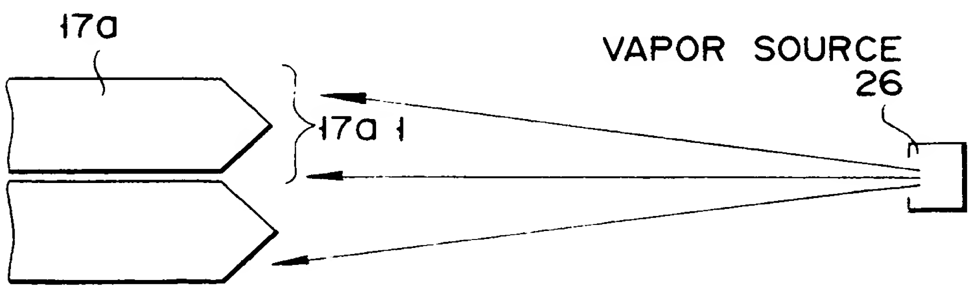
F I G. 1



F I G. 2



F I G. 3



F I G. 4

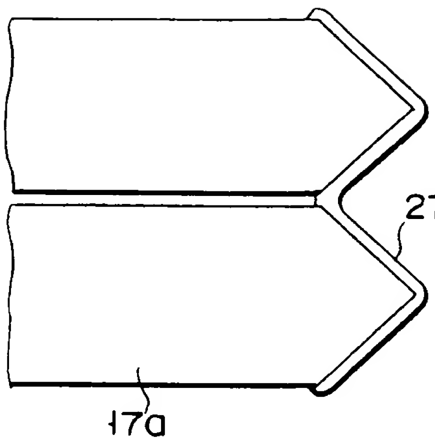


FIG. 5

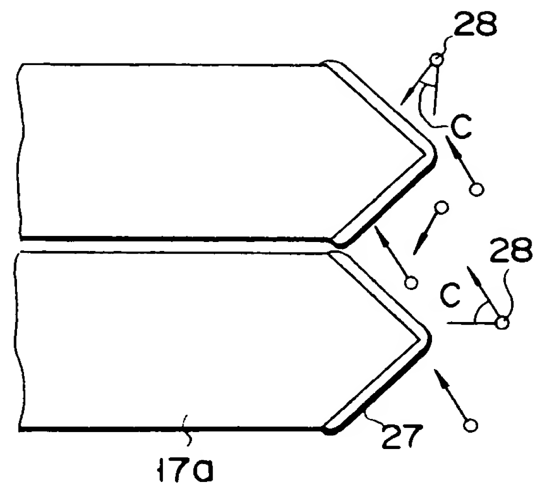
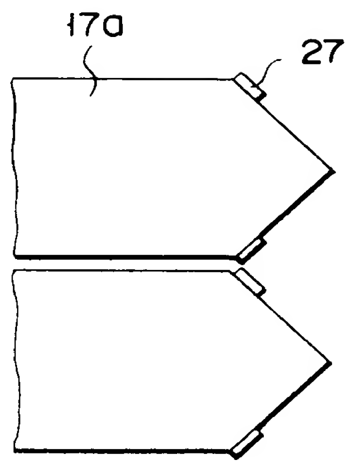


FIG. 6

FIG. 7



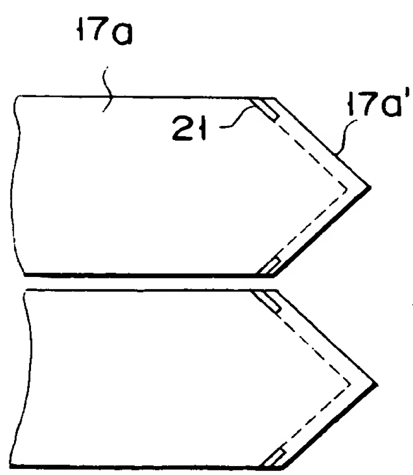


FIG. 8

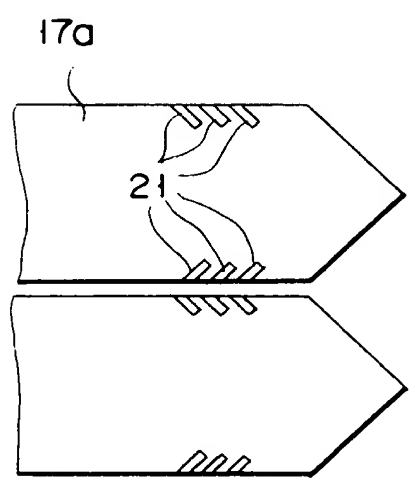


FIG. 9

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 11 7679

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	PATENT ABSTRACTS OF JAPAN vol. 8, no. 139 (E-253)(1576) 28 June 1984 & JP-A-59 049 141 (SHIMAZU SEISAKUSHO) 21 March 1984 * abstract * *	1-3	H 01 J 31/50 H 01 J 29/38 H 01 J 9/12
A	US-A-3 852 133 (J.M. HOUSTON) * Abstract * * figure 9 * * column 1, line 61 - column 2, line 47 * * column 8, line 31 - line 48 * *	1-3	
A	US-A-4 011 454 (S.J.LUBOWSKI ET AL.) * Abstract * * figures 2A-H * * column 1, line 28 - column 2, line 58 * * column 4, line 53 - column 5, line 17 * * column 8, line 42 - column 9, line 18 * *	1,3	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H 01 J
G 21 K

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	03 February 92	DAMAN M.A.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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